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Life cycle analysis of municipal solid waste management possibilities in Asturias, Spain

Directive 1994/62 concerning packaging and packaging waste and Directive 1999/31 relative to waste disposal will substantially modify the management and treatment of Municipal Solid Waste (MSW) in Europe. In this study, a Life Cycle Analysis has been carried out of the different possibilities of managing Municipal Solid Waste in Asturias. The "Integrated Waste Management" (IWM-1) model was employed, analysing the different alternatives for collection and treatment of MSW. This model predicts overall environmental burdens of MSW management systems and includes a parallel economical model. The sources of costs in the different systems of collection and treatment of MSW were considered in the economical analysis, as well as the sources of resource gathering that may be obtained via the sale of recovered materials. What emerges from this study is the soundness of management strategies based on biological treatment technologies in comparison with thermal treatments, together with the need to increase the level of collection at source.

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Introduction

The management of MSW in Spain and in Europe will change substantially over the next few years as a result of Directive 1994/62 (transposed in Law 11/97) and the recent coming into force of European Directive 1999/31 (transposed in Royal Decree 1481/2001). Until now, the most widely employed treatment of MSW in Spain has been landfilling, representing a percentage of 70.4% of the total, including sanitary and uncontrolled landfills, according to data from the National Plan for Municipal Waste (NPMW), approved by the Resolution of 13 January 2000.

The aims of both Directive 1999/31 and the NPMW are to slow down the increase in volume of waste generated, to achieve a comprehensive Community policy as well as to bring about sustainable development. Likewise, it is planned to foment the valorisation of waste and a reduction in the amount sent to landfills. The aim of this Directive is to provide, by way of stringent operational and technical requirements concerning waste and landfills, for measures, procedures and guidance to prevent or reduce as far as possible negative effects on both the local environment, in particular the pollution of surface water, groundwater, soil and air, as well as the global environment, including the greenhouse effect, as well as any resulting risk to human health from landfilling of waste, during the whole life-cycle of the landfill. The specific objectives of this Directive are: (1) by no later than five years after the 16th July 2001, biodegradable Municipal Solid Waste going to landfills must be reduced to 75% of the total amount (by weight) of biodegradable Municipal Solid Waste produced in 1995 or the latest year before 1995 for which standardised Eurostat data is available; (2) by no later than eight years after the aforementioned date, biodegradable Municipal Solid Waste going to landfills must be reduced to 50%; and (3) by no later than 15 years after the above date, biodegradable Municipal Solid Waste going to landfills must be reduced to 35%.

In Spain, the NPMW establishes that a total of 9% of the MSW generated by the end of 2001, and a total of 17.7% in 2006 should be treated by incineration with energy recovery. An advantage of the application of this valorisation technique is the minimum production of residues (about 90% reduction in volume and 70% in weight). Other advantages are that the ash produced is more inert than MSW along with the possibility of obtaining energy from the incineration process. The main inconvenience is that the gas produced in the incineration process must be treated.

With respect to biological treatments, the NPMW establishes that 18.5% of the MSW generated by the end of 2001, and a total of 24.2% in 2006, should be treated by composting.

Faced with this new situation in the management of MSW and in order to find the most adequate option from both environmental and economic viewpoints, this article proposes different management strategies applied to the Central Landfill of the Principality of Asturias that comply with the stipulations contained in the NPMW and in Directives 1994/62 and 1999/31, employing the Life Cycle Analysis (LCA) tool to evaluate them.

LCA constitutes a management tool that is used to evaluate the environmental behaviour of a product, process or activity throughout its entire life cycle in the most objective way possible. To do so, it is necessary to identify and quantify both the use of materials and energy as well as emissions of all types to the environment. The provoked impact is thus determined and the possibility of carrying out environmental improvements is evaluated (Randa Group, 1996, Fava *et al.* 1992).

The study includes the complete life cycle of the product, process or activity, taking into consideration the stages of extraction and processing of raw materials, manufacturing, transport and distribution, use, reuse and maintenance, recycling and end disposal. The aims of the present study consist in detecting the main sources of costs in the different models for the collection and treatment of MSW, analysing the fund-raising resources that may be obtained via the sale of recovered materials, recognising the value of each proposed situation and detecting the influence of decreasing the amount of MSW generated and the distance to the landfill, as well as an interest in applying composting or biomethanisation techniques (Rodríguez-Iglesias *et al.* 2000).

Life cycle analysis of MSW management

Waste management may be divided in a general way into two fundamental areas: conservation of resources and environmental pollution. When evaluating the pollution that is generated, one should not observe solely the last stage of production, but the entire process. Thus, for example, it may be determined that from a certain haulage distance onwards, the pollutant load generated by the recycling of used paper is higher than that of using virgin raw material. This same argument may be used in the depositing of material in a landfill to be used to generate biogas: the energy recovered in the form of biogas may, in some cases, compensate the costs of transport, manipulation and depositing of the waste (White *et al.* 1995).

The environmental benefit of recycling does not increase linearly with the amount of recycled material. To reach high rates of recycling, it becomes necessary to collect material from disperse sources, which means high costs of transporting material, thus decreasing the energy saving achieved by recycling it.

In a LCA of a MSW management system, the intermediate processes of domestic auto-recycling, incineration or composting are not included. When speaking of waste, what is referred to is its end disposal in the environment (generally in a landfill, incineration, etc.). However, in the strict sense, only ashes (after incineration) and end materials after landfill transformations (leachates, gases) may be considered as the final stage in the life of a product. In the analysis, it is important to know the moment at which the materials acquire and lose the value that allows their subsequent use in another process, so as to carry out the economic analysis of the whole LCA.

As far as the recycling industry is concerned, the materials extracted from the waste management system generally acquire a positive value in the balance of the system and start up a new cycle. These materials are excluded from the LCA until they exit the recycling-use-recycling system. In some cases, recycling supposes a negative economic balance; such is the situation, for instance, of the recycling of plastic in Germany, where there exist subsidies for its selective collection and transformation into recycled plastic resin (Billigmann, 1996).

The LCA described in this paper was applied to the Central Landfill of the Principality of Asturias, managed by COGERSA, where 99% of the MSW generated in our Autonomous Community is disposed of, the equivalent of 400,000 t/year. The leachates are collected and piped to a specific treatment plant and the biogas is used to generate energy, exporting more than 35 million kW-h per year to the electricity grid. The biogas is also used as fuel in the incinerator for hospital waste (Rodríguez-Iglesias *et* *al.*1998, Rodríguez-Iglesias *et al.*2000b). There also exists a classifying plant for the waste materials from the selective collection of MSW.

Methodology

The LCA described was carried out using the "Integrated Waste Management" (IWM-1) Model, developed specifically to carry out LCA of MSW management systems. The IWM-1 Model predicts overall environmental burdens of Municipal Solid Waste management systems and includes a parallel economical model. The model was designed as a decision-support tool for waste managers in both industry and local government, who need to decide between various options for waste management. The model is used in Europe, South America and Asia to help design or optimize both regional and local waste management systems (Mc Dougall *et al.* 2000, Mc Dougall 2001, Clift *et al.*2000).

To carry out the LCA inventory of the landfill, all the environmental loads (atmospheric pollution, liquid effluents, solid waste, noise, smells, etc.) corresponding to the input effluents were taken into account, as well as those corresponding to the effluents from the plant itself. This input information must be transmitted to the following process in the landfill and to the by-products obtained there (gas, electrical energy, etc.). This is done by means of a vector that contains all the information about all the possible types of pollution. Each product or process flow has an associated vector with all the information on the pollution generated during the entire life cycle. This eco-vector, , is a multidimensional vector in which each dimension corresponds to a particular pollutant.

Each mass flow in the process (kg/s) has an associated eco-vector, ν, whose elements are expressed in mass (kg of pollutant per kg of product) or other units, such as energy (kJ/kg) or Environmental Load (EL) per unit of mass, for flows not measurable in units of mass, such as radiation or acoustic intensity.

The following expression shows a mass eco-vector, ν_m, in which the environmental loads are grouped together in types of environmental impact:

$$\nu_m = \left| \begin{array}{l} \text{kg/kg or EL/kg} \\ \text{Atmospheric emissions} \\ \text{Liquid effluents} \\ \text{Solid wastes} \\ \text{Radiation} \\ \text{Other EL} \end{array} \right| \qquad (1)$$

The mass flow M (kg/s) of a process multiplied by the corresponding vector ν_m gives the amount of pollutants P (kg/s) or (EL/s) generated up to this stage of the process. The amount of EL/s indicates the environmental impact per unit of time of the process:

$$M \cdot \nu_m = P \qquad 2)$$

An energy eco-vector ν_e is likewise defined for the energy flows, whose elements are expressed as mass (kg of pollutant per kJ). That is, the energy flow E (kW) multiplied by the corresponding vector ν_e gives the pollutant flow, the vector P (kg/s) or (EL/s) generated when producing this energy:

$$E \cdot \nu_e = P \qquad (3)$$

These expressions indicate that the environmental load of the mass and energy flows may be treated in conjunction, as the product of a flow multiplied by the corresponding vector is always the pollutant flow P expressed in kg/s or EL/s.

Each influent has an associated eco-vector and its content must be distributed among the effluents of the system. The balance of each of the elements of the eco-vector must be satisfied, such that the total amount of pollutant exiting the system must be equal to the amount of pollutant entering this system plus what is generated in the process itself minus what is transformed to other substances.

For this balance to be possible, the process effluents are divided into products or waste. In the methodology employed, the waste effluents have eco-vectors with negative elements corresponding to the pollutants they contain. The pollutant load of the influents plus the waste effluents must be distributed among the products of the process. The pollutant balance must always be satisfied. The pollutant load inventory or balance of a processing plant is carried out in a similar way to the mass balance. The plant is divided into units or sub-systems and the system of equations that allows the eco-vectors of the effluents and intermediate flows to be calculated are set out and solved in each of these. The solution of the whole system allows us to gain detailed knowledge of the origin of the pollution that is attributed to each of the plant's products.

The balances that we have considered are continuous (as is the addition of material to the landfill), though discrete analyses may also be made by changing the calculation base.

If we consider a generic system as represented in Fig. 1, with n inputs of raw materials and energy and n outputs of products and residues, the overall environmental load balance will be defined by the following equation

$$\sum_{i=1}^{n} \mathrm{IP}_i \cdot \nu_{m,\mathrm{IP}_i} + \sum_{i=1}^{n} \mathrm{IE}_i \cdot \nu_{e,\mathrm{IE}_i} - \sum_{i=1}^{n} \mathrm{W}_i \cdot \nu_{\mathrm{m},\mathrm{W}_i} = \sum_{i=1}^{n} \mathrm{P}_i \cdot \nu_{\mathrm{m},\mathrm{P}_i} \qquad (4)$$

Where

IP_i are the mass inputs

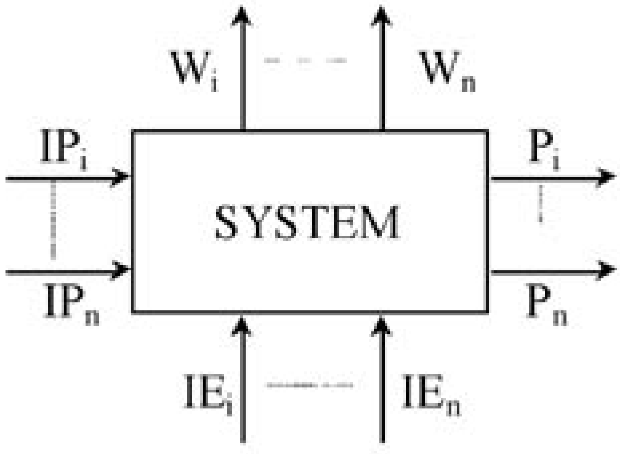

Fig. 1: Overall environmental load balance.

IE_i are the energy inputs
P_i are the output flows (products and subproducts)
W_i are the residues
ν_m, ν_e are the mass and energy eco-vectors of the flows

The IWM-1 Model was applied to the following nineteen situations:

1. Currently existing situation: sanitary landfilling with biogas recovery and selective collection.
2. Situation No. 1 applying Law 11/97 of Packaging and Packaging Waste (50% recovery of materials and 25% recycling).
3. Situation with domestic classification of MSW, incineration with energy recovery of the selectively collected combustible fraction (paper, cardboard and packaging), the remaining materials being sent to the landfill.
4. Situation with selective collection and recovery of materials. The remaining materials are sent for incineration with energy recovery.
5. Situation No. 3, though reducing the volume of MSW generated by 10%.
6. Situation No. 3, though reducing the volume of MSW generated by 20%.
7. Situation No. 3, though reducing the volume of MSW generated by 30%.
8. Situation No. 4, though reducing the volume of MSW generated by 10%.
9. Situation No. 4, though reducing the volume of MSW generated by 20%.
10. Situation No. 4, though reducing the volume of MSW generated by 30%.
11. Situation No. 4, though reducing the volume of MSW generated by 10% and decreasing the distance to the treatment plant to only 2 km.
12. Situation No. 4, though reducing the volume of MSW generated by 20% and decreasing the distance to the treatment plant to only 2 km.
13. Situation No. 4, though reducing the volume of MSW generated by 30% and decreasing the distance to the treatment plant to only 2 km.
14. Selective collection and composting of the organic fraction separated at source, recovery of the valuable materials and landfilling of the residues.
15. Situation No. 14, though doubling the selling price of the compost.
16. Situation No. 14, though trebling the selling price of the compost.
17. Selective collection and biomethanisation of the fraction separated at source with composting of the residual sludge, selective recovery of the valuable materials and landfilling of the residues.
18. Situation No. 17, though doubling the selling price of the compost.
19. Situation No. 17, though trebling the selling price of the compost.

When applying a LCA to a product, the functional unit is defined in terms of the system's output, i.e. the product per kg of product made. When applying a LCA to waste, the functional unit is defined in terms of the system's input, i.e. the waste. Thus the functional unit in our case will be the total waste produced in the Principality of Asturias in one year. This study considers the Life Cycle of waste from the moment it becomes waste by losing value, to the moment it regains value or leaves the waste management system as an emission; this is our system boundary.

The data used with respect to the number of inhabitants, the composition of the refuse and fuel expenses were supplied by COGERSA.

COGERSA collects organic materials on a daily basis and the remaining materials on a weekly basis. It is estimated that each collection team covers an average of 150 km (data supplied by COGERSA), with an average consumption of 10 l of fuel per 100 km.

In this model, paper, cardboard and plastic are considered burnable waste with energy recovery.

The basic idea considered was that of reducing the use of the landfill as an end point for the MSW as far as possible, in line with the tendency reflected in Directive 1999/31.

The assumptions made in this study are:

- the classifying plant, the incinerator and the landfill are all located within a radius of 2 km;
- the ashes produced in the incineration will be deposited in the toxic waste landfill;
- leachate collection efficiency: 90%, biogas recovery: 75%;
- the yield of the centralised system of MSW classification is 8%;

- selling price of recycled materials: 0.30 Euros/kg for situation No. 4, bearing in mind that an increase in their supply may lead to a decrease in their price;
- batteries, aluminium cans and uncommon metals are considered non-ferrous materials;
- packaging and domestic bags for MSW are considered to weigh approximately 50 g, 95% being made of plastic film;
- textile materials are not considered.

The Global Warning Potential (GWP) was used to characterize the global warming impact. GWP is the aggregate loading of greenhouse gases expressed as CO_2 equivalents over a 100-year time horizon, as proposed by the Intergovernmental Panel on Climate Change (IPCC) in 1996. The gases considered in our case were: CH_4, CO_2 and N_2O (the contribution of CFC is negligible). This term also includes the CO_2 emissions from biologically based C-sources.

Data on the amount of leachate produced in the landfill site and its composition were supplied by COGERSA. A production of 310.4 L/t MSW was used and the horizon applied was 30 years, established in Royal Decree 1481/2001 (transposition of Directive 1999/31) as the minimum period for controlling and monitoring emissions in a landfill after its closure.

Heavy metals were also characterised, including waterborne emissions and airborne emissions, and are expressed in equivalent tons of lead. The characterisation parameters used were taken from EcoIndicador 95 (Goedkoop, 1995). The metals taken into account were: cadmium, mercury, manganese, lead, arsenic, boron, barium, chromium, copper, molybdenum, and nickel. The overall thermal energy consumption, emissions and solid waste generated by electricity production are based on the Union for the Connection Production and Transport of Electricity Model (UCPTE, 1994). The Life Cycle Inventory (LCI) data for fuels, including production and use, is based on BUWAL 250 (1998). The emissions factors for the incineration process are based on the International Ash Working Group (IAWG) (1997) and US EPA (1997). The model used to estimate emissions from the incineration process is based upon the model developed by the US EPA; this approach splits the emissions into non metal emissions and metal emissions, allowing a different modelling approach to be taken for each group of emissions. The non-metal emissions are calculated using a stoichiometric approach involving a combustion equation and ultimate analysis of the components of solid waste, while metal emissions are based on the metals composition of individual waste components. This model also includes technological issues. In composting, the emission factors were taken from The German Federal Association for Quality Compost (1997) and from Schauner (1995). The energy consumption and emissions factors are based on BUWAL 250.

Results and discussion

Fig. 2 presents the total costs for each situation analysed. The most economic situations occur with recovery of compost (cases 14 to 16). Likewise, we see that increasing the selling price of compost results in a significant decrease in costs. Biomethanisation also gives rise to an advantageous economic situation with respect to total costs (cases 17 to 19). It is worth noting that the current situation proves to be economically better than that of applying any other alternative (cases 1 and 2), due to the high level of production and recovery of the biogas in the landfill.

Fig. 3 presents the total costs per treated ton. This graph reflects what was stated above: the production of compost is important economically-speaking and reducing the volume of treated MSW supposes an increase in the total cost per managed ton. The current situation, biomethanisation and composting are found to render positive results. As can be observed in Fig. 3, decreasing the distance to the depositing centre (alternatives 11 to 13 versus alternatives 8 to 10) decreases cost by around 14%.

Fig. 4 presents the cost per person receiving the service per year. A surcharge of approximately 20 Euros per person-year exists for situations with incineration, which would be the equivalent of an increase in collection rates per household of approximately 48 Euros per year, considering 2.5 persons/household. In the case of composting, this increase would be between 12 and 17 Euros per person; and in the case of biomethanisation, between 14 and 17 Euros. The increase in the household rate in these two last cases would be between 30 Euros per year for the most favourable situation and 42 Euros per year in the most unfavourable.

Fig. 5 presents the net employment of energy. A saving of 30% can be observed in this graph in the net use of energy when the volume of MSW generated is reduced (cases 7, 10 and 13). The contrary situation –maximum use of energy– occurs in the situations of manufacturing compost and in biomethanisation. It is worth noting that decreasing the distance to the treatment plant does not suppose a significant improvement in the total use of energy. In all cases, incineration presents a higher energy efficacy, though it is the most unfavourable technique from an economic viewpoint.

Fig. 6 presents the final volume of MSW sent to the landfill. The volume of MSW decreases quite substantially when thermal treatment via incineration is employed,

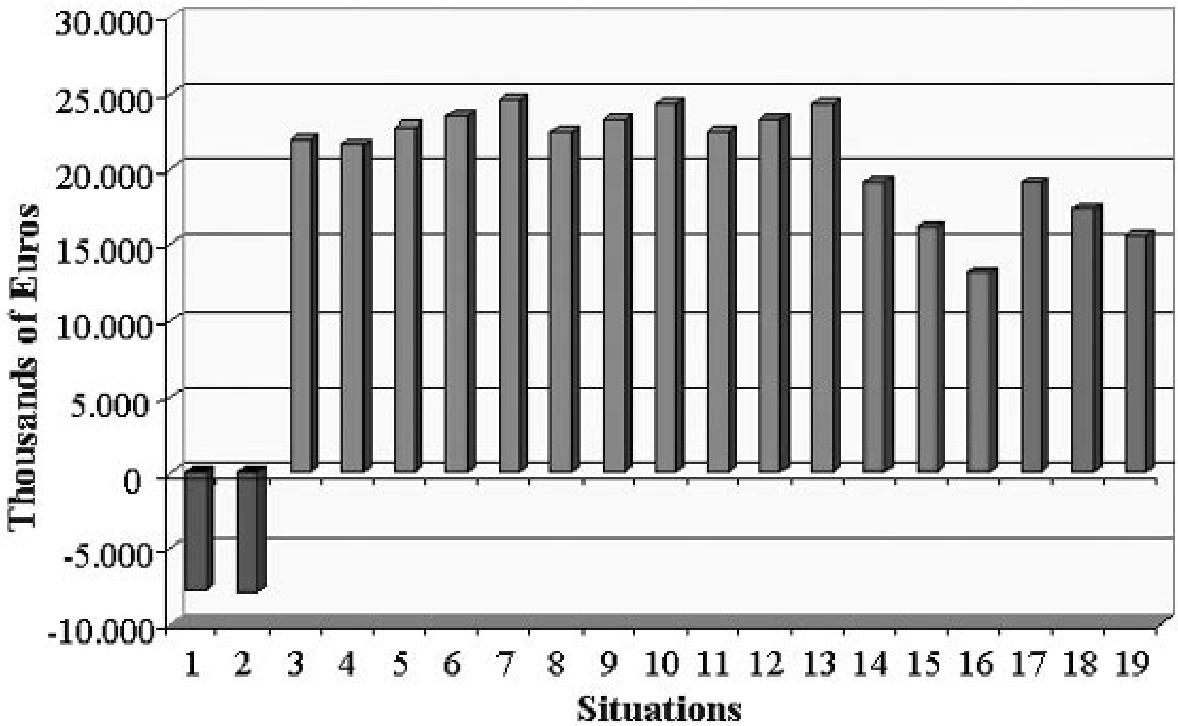

Fig. 2: Total costs resulting from the application of LCA to the different situations studied.

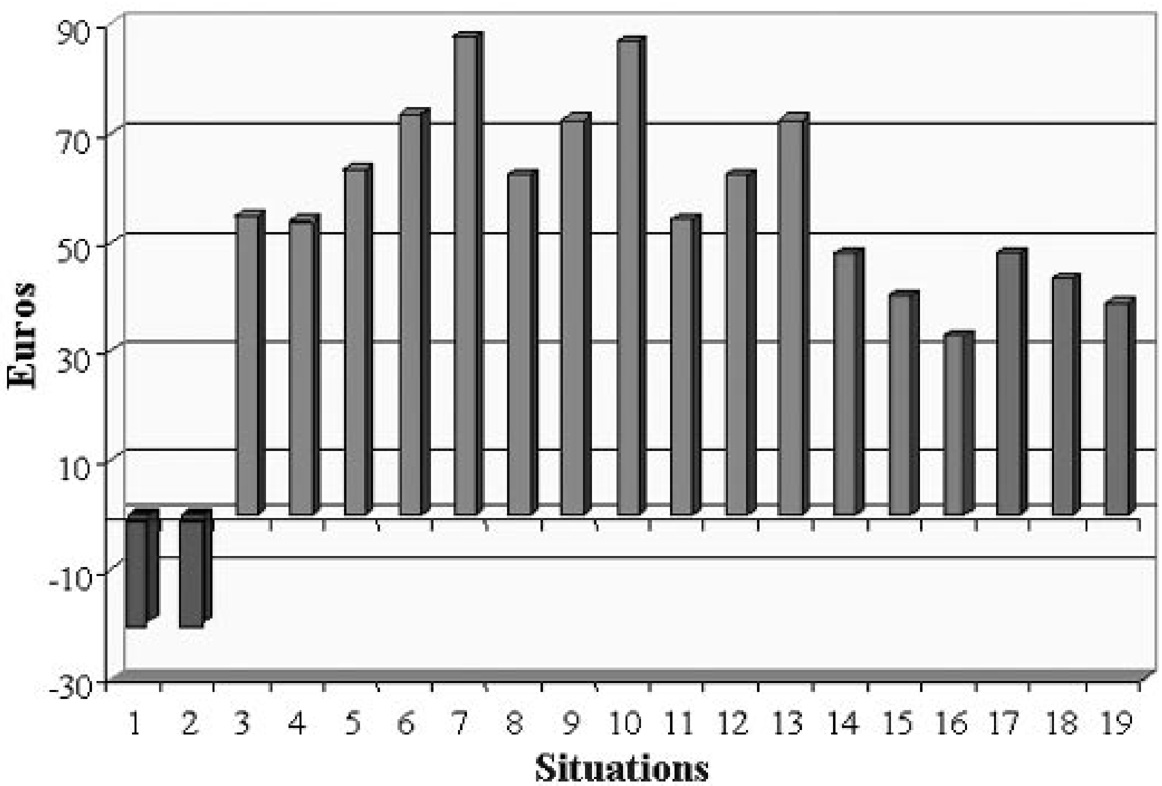

Fig. 3: Cost per ton of managed MSW for the different situations studied.

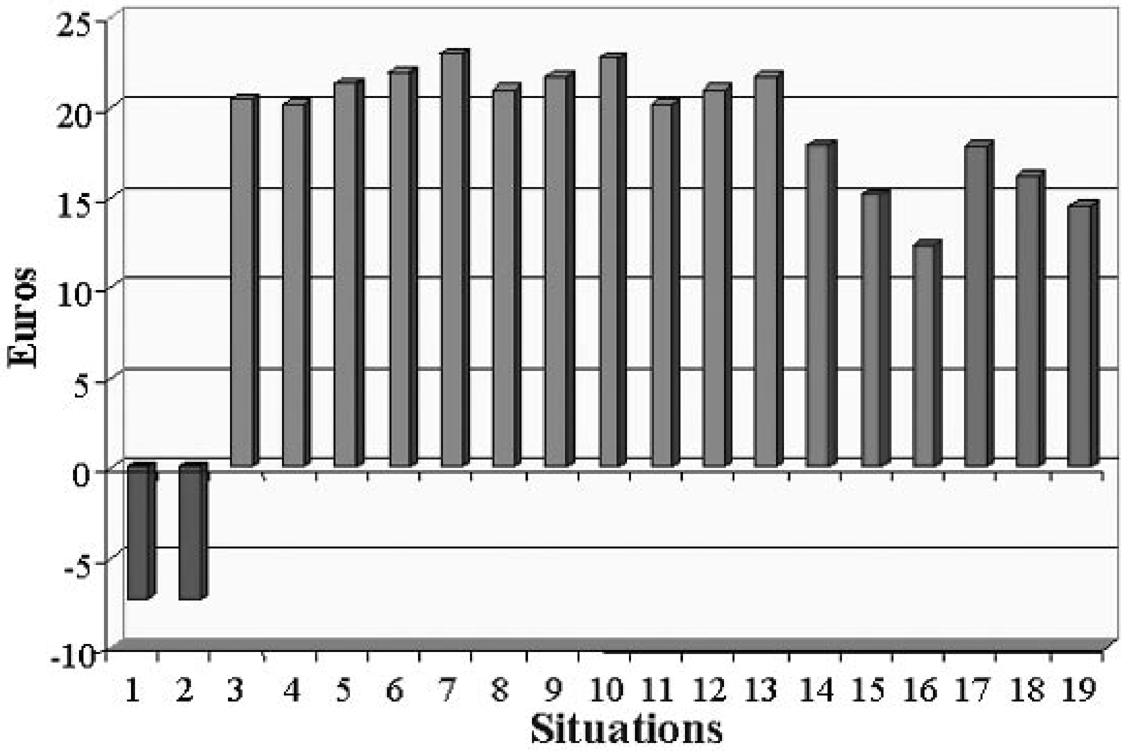

Fig. 4: Unit cost per person receiving the service for the different situations studied.

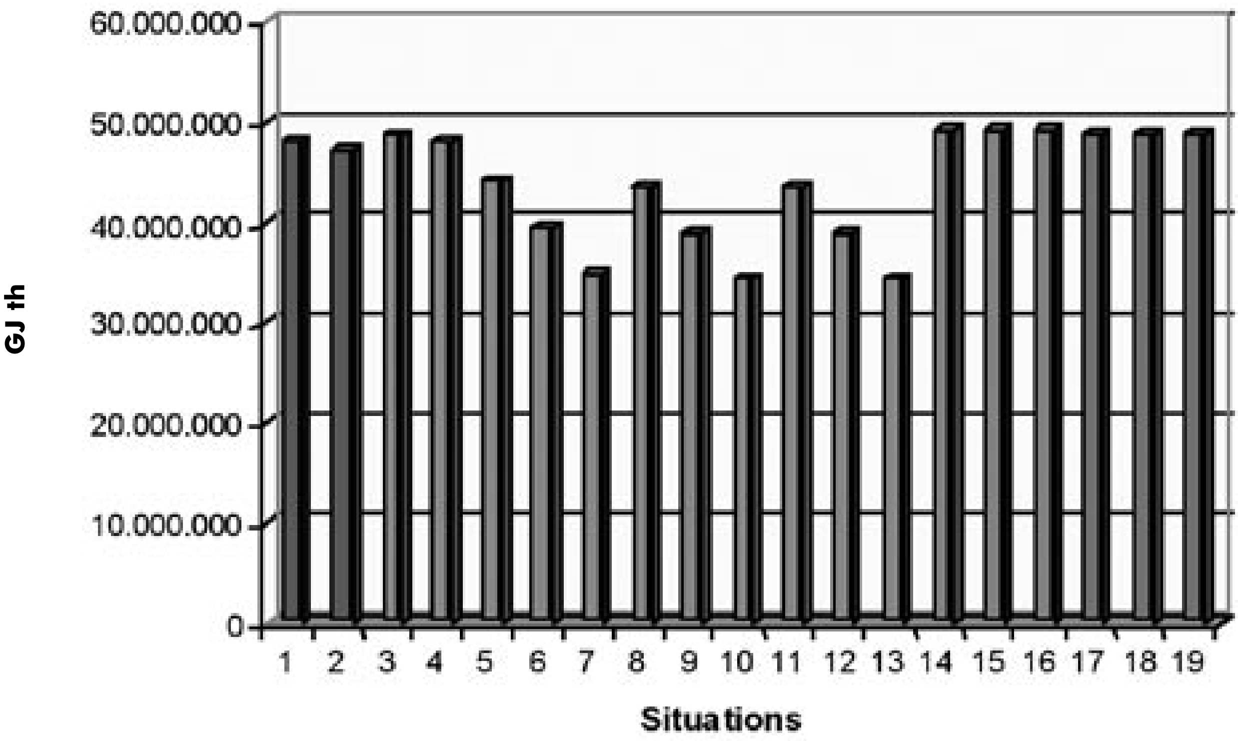

Fig. 5: Net employment of energy for the different situations studied.

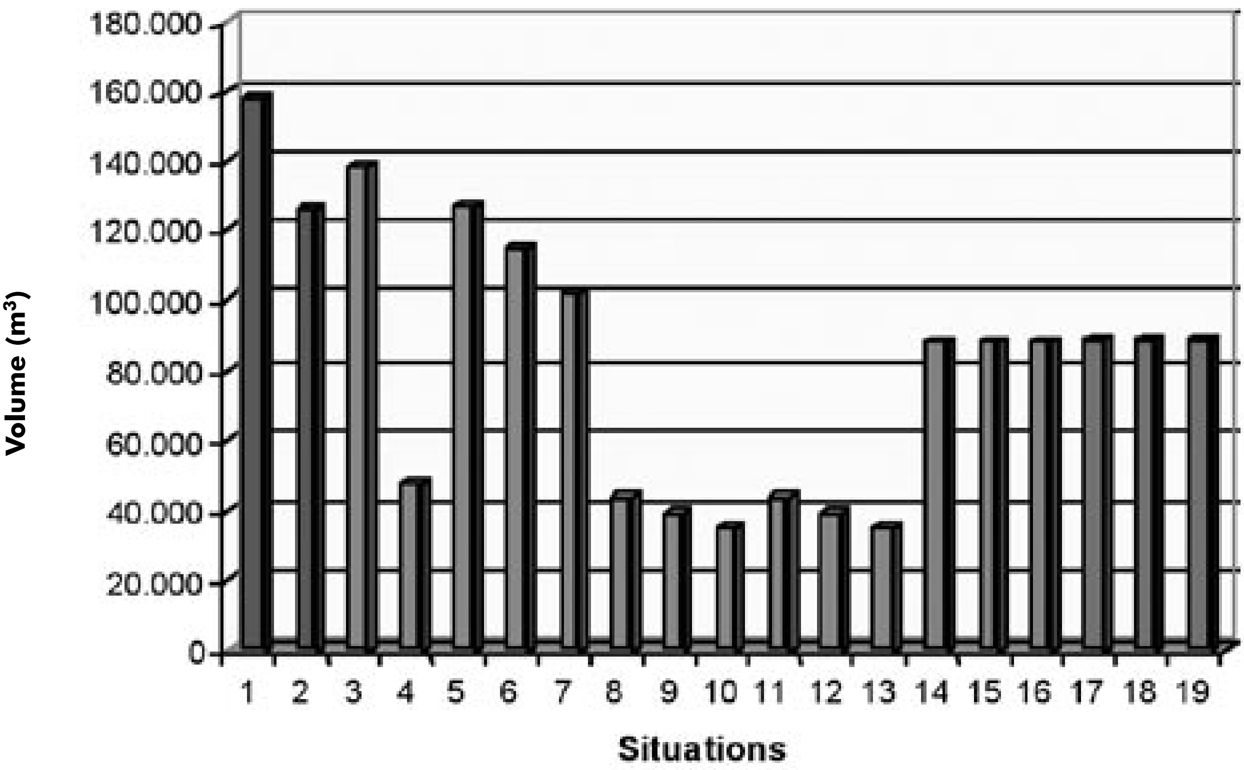

Fig. 6: Final volume of MSW deposited per year in the landfill for the different situations studied.

given that in these situations only the ashes and some incombustible material are deposited in the landfill. The current situation is the one that contributes the most volume to the landfill. The reduction in volume of MSW generated has favourable repercussions. The situations of composting and biomethanisation reduce the total volume, though not so much as when employing incineration.

Fig. 7 presents the total production of dioxins and furanes in Equivalent Toxicity (EQT). The greater amounts produced in incineration stand out, as well as the low levels of generation in the biological treatments. The maximum efficiency of combustion systems would permit a reduction in the generation of these hazardous products. However, the generation of dioxins and furanes is situated below current emission limits (0.1 ng/Nm3).

Fig. 8 presents the emissions of greenhouse gases (CH_4, CO_2, N_2O), expressed as CO_2 equivalents (Global Warning Potential). Worth noting here is the fact that the current situation and biological treatments suppose a greater contribution than the use of incineration with energy recovery, as is to be expected bearing in mind the greater energy consumption. Logically, the reduction in volume of MSW generated contributes positively to a reduction in the GWP.

Fig.s 9 and 10 present the estimated emissions of NOx and SO_2 into the atmosphere. As in the previous case, these emissions are greater if biological treatments are employed, in which cases the greater contribution is produced in the collection and transport stages as a result of emissions from mobile sources. A possible alternative in order to reduce the emissions of SO_2 consists in using bio-diesel or natural gas, given the low sulphur content of these fuels.

Fig. 11 shows the total emissions of heavy metals, expressed in equivalent tons of lead, for the different situations. The obtained values include airborne emissions and waterborne emissions. As can be seen in this Fig., all situations with some thermal treatment considerably increase heavy metals emissions, especially to the atmosphere. For instance, alternatives using biological treatments present emissions of around 0.35 t/year, whereas incineration processes present values of between 6.5 and 8.9 t/year.

Fig. 12 presents the total recovery rate of materials. The highest recovery rate (57%) is produced with composting, while in the processes of incineration the recovery rate is situated around 20%. It should be noted that the current situation is the one that presents the lowest recovery rate, at only 13%.

Fig. 13 presents the recovery of glass and paper. It can be seen that the recovery of paper is very high when applying biological treatments, taking into account the higher yield produced by separation of components, while incineration recovers a lower amount, as it uses paper as a fuel.

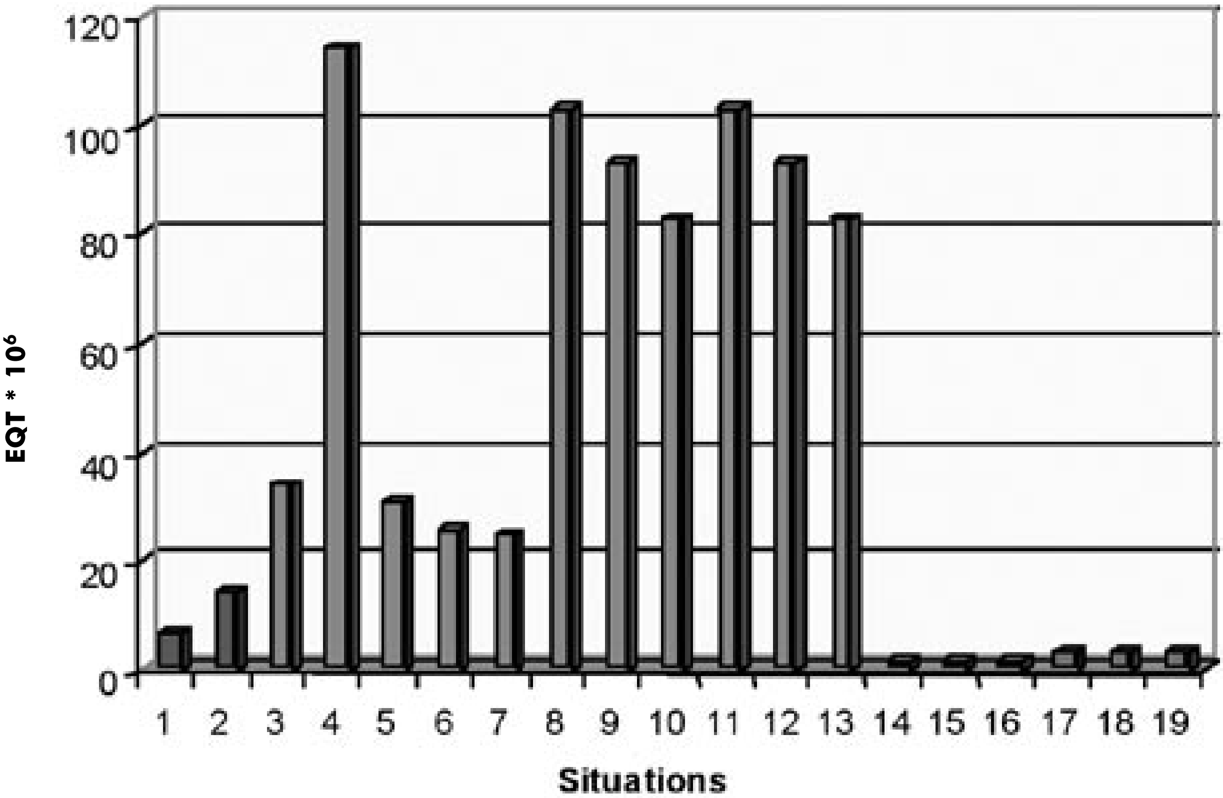

Fig. 7: Total production of dioxins and furanes for the different situations studied.

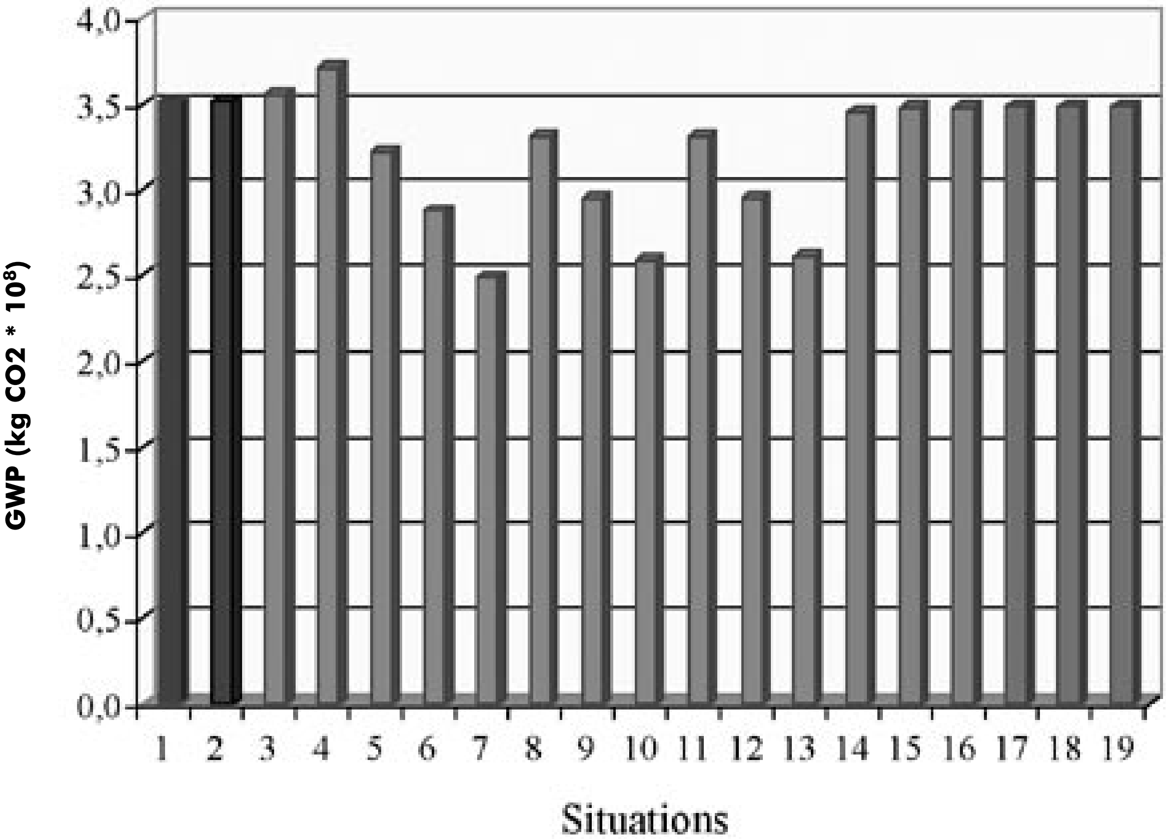

Fig. 8: Global Warning Potential in the different situations studied.

Likewise, as the production of MSW decreases, so does recovery –cases 8 to 10 and 11 to 13. As regards glass, recovery is similar in all cases and varies slightly with the generation of residues.

After the characterization stage, processes of normalisation and weighting were carried out following the EcoIndicator 95 methodology. Normalisation is useful to evaluate the environmental profile significance of the characterization stage. Using EcoIndicator 95, one single score may be calculated for the total environmental impact based on the calculated effects that an average European causes in a year. After normalisation, a weighting factor that considers the magnitude of the different impacts is applied. The weighted impact categories were: greenhouse effect, acidification, eutrophication, heavy metals, carcinogens, winter smog and summer smog. The substances considered for calculating the mentioned impacts and the results obtained in the normalisation and weighting stage for Situations 1, 4, 14 and 17 are shown in Tables 1 and 2, respectively. These situations were chosen due to their being the most likely situations to prosper. Among the different alternatives studied, the one involving incineration presents higher values than the others, especially in the heavy metals and carcinogens categories. Notice that these categories are practically negligible in those alternatives with biological treatments; the choice of a biological treatment strategy hence entails a considerable reduction in the emissions of heavy metals and carcinogens. The impact category with the next highest score was the GWP. As can be seen in Table 2, Situation 14 (with composting) presents the lowest values in this impact category, thus being the most favorable.

Conclusions

In the analysis of economic costs, the strategies that prove to be the most advantageous are those that include biological treatments as opposed to those that employ incineration. The costs per treated ton in the case of incineration vary between 54 Euros for the most favourable situation and 87 Euros in the most unfavourable. Costs can be balanced both in biomethanisation as well as composting by the sale of the compost generated. To reach this balance, it would be necessary to sell the compost at 0.22 Euros/kg in the case of composting and at 0.35 Euros/kg in the case of biomethanisation. If it were decided to provide compost at zero cost, the price per treated ton would be approximately 52 Euros for biomethanisation and 55 Euros for composting.

From the energy viewpoint, the situations that achieve better exploitation of energy are those that use incineration, whereas biological treatments require higher energy consumption, fundamentally due to the need to intensify selective collection.

The emissions of CO_2, NOx and SO_2 to the atmosphere are slightly higher in the management systems employing biological treatments due to the emissions of mobile sources in the stages of waste transport and collection,

Table 1: Emissions considered for calculating environmental impacts, according to ***Ecoindicator*** 95

	Airborne emissions	Waterborne emissions
Greenhouse Effect	carbon dioxide, methane, nitrous oxide	
Acidification	sulfur oxides, nitrogen oxides	
Eutrophication	ammonium, nitrates, nitrogen oxides, phosphorus and phosphates	Chemical Oxygen Demand, organic nitrogen, ammonium, nitrates and total phosphorus
Heavy metals	cadmium, mercury, manganese, lead, arsenic, boron, barium, chromium, copper, molybdenum, and nickel	cadmium, mercury, manganese, lead, arsenic, boron, barium, chromium, copper, molybdenum, and nickel
Carcinogens	arsenic, chromium, nickel, aromatic hydrocarbons, and polycyclic aromatic hydrocarbons (PAH)	
Winter smog	dust and sulfur oxides	
Summer smog	hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, polycyclic aromatic hydrocarbons and volatile organic compounds	

Table 2. Normalisation and weighting applied to different situations using EcoIndicator 95

Normalisation					
	Normalisation factor	Situation 1	Situation 4	Situation 14	Situation 17
Greenhouse	0.0000742	26106.1	27512.2	25597.7	25867.1
Acidification	0.00888	3259.3	3281.9	2986.0	3277.6
Eutrophication	0.0262	1041.3	921.3	472.9	500.5
Heavy metals	17.8	5645.3	158085.9	6299.2	6186.7
Carcinogens	106	0.26	71225.4	0.09	0.09
Winter smog	0.0106	1179.4	1188.7	1199.1	1188.5
Summer smog	0.0507	-275.8	-34.2	-239.2	-451.3
Total		36956	262181	36316	36569
Weighting					
	Weighting factor	Situation 1	Situation 4	Situation 14	Situation 17
Greenhouse	2.5	65265.2	68780.5	63994.3	64667.8
Acidification	10	32593.6	32818.9	29860.0	32776.5
Eutrophication	5	5206.7	4606.4	2364.5	2503.0
Heavy metals	5	28226.4	790429.8	31495.9	30933.5
Carcinogens	10	2.6	712254.4	0.91	0.92
Winter smog	5	5896.8	5943.4	5995.4	5942.9
Summer smog	2.5	-689.6	-85.6	-597.9	-1128.4
Total		136502	1614748	133112	135696

Situation 1: Currently existing situation: sanitary landfilling and selective collection
Situation 4: Selective collection and recovery of materials. The remaining materials are incinerated with energy recovery
Situation 14: Selective collection and composting of the organic fraction separated at source, recovery of valuable materials and landfilling of residues.
Situation 17: Selective collection and biomethanisation of the organic fraction separated at source with composting of the residual sludge, recovery of valuable materials and landfilling of residues.

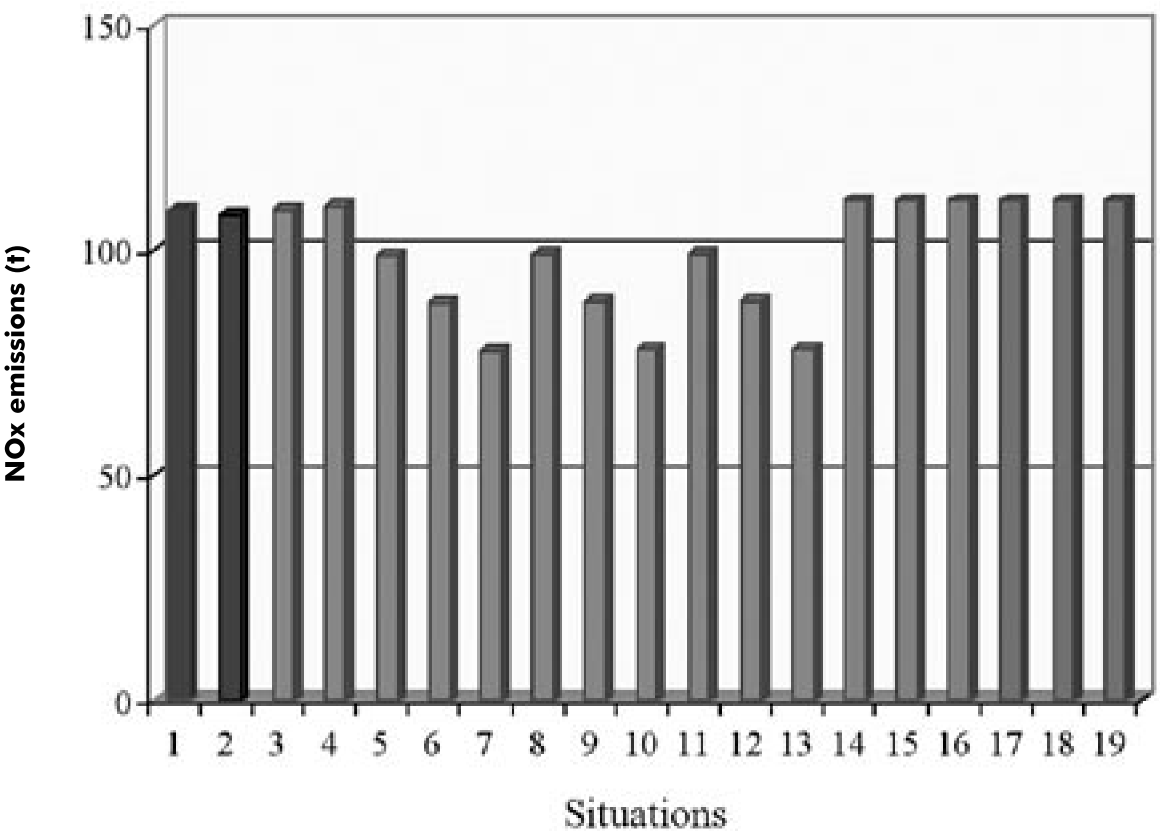

Fig. 9: Airborne emissions of NOx for the different situations studied.

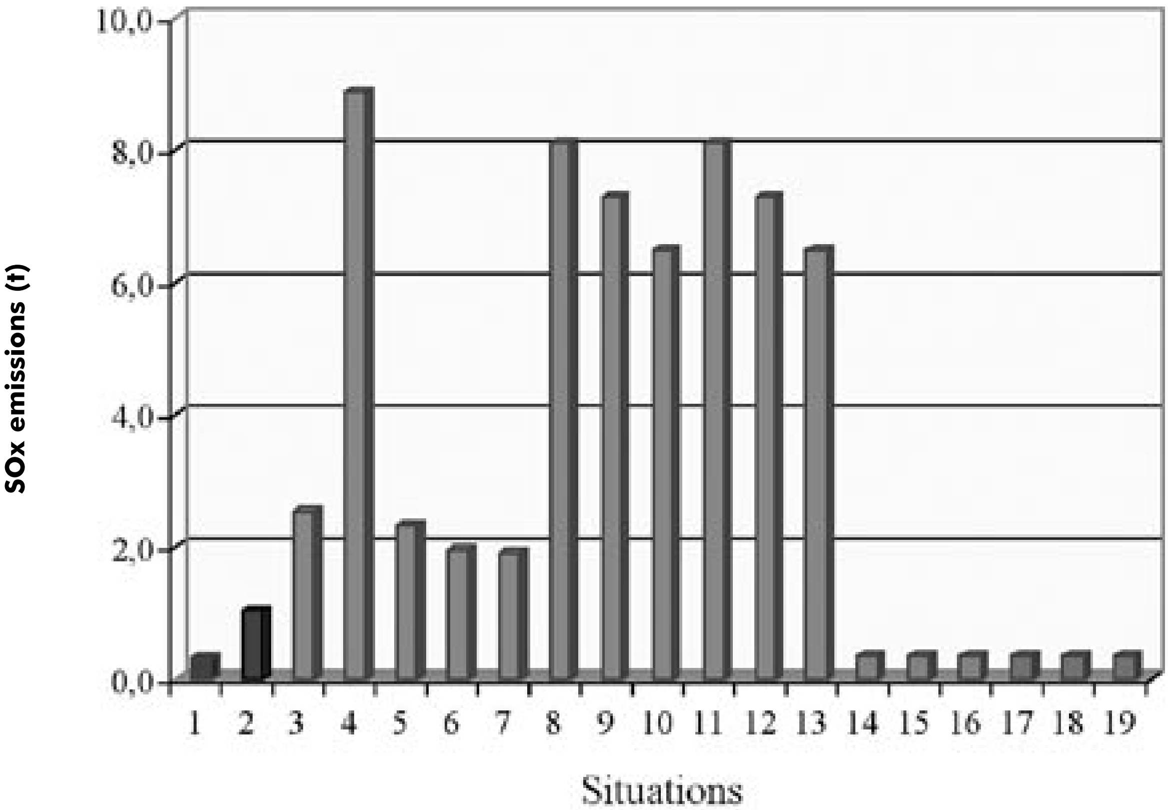

Fig.10: Airborne emissions of SO2 for the different situations studied.

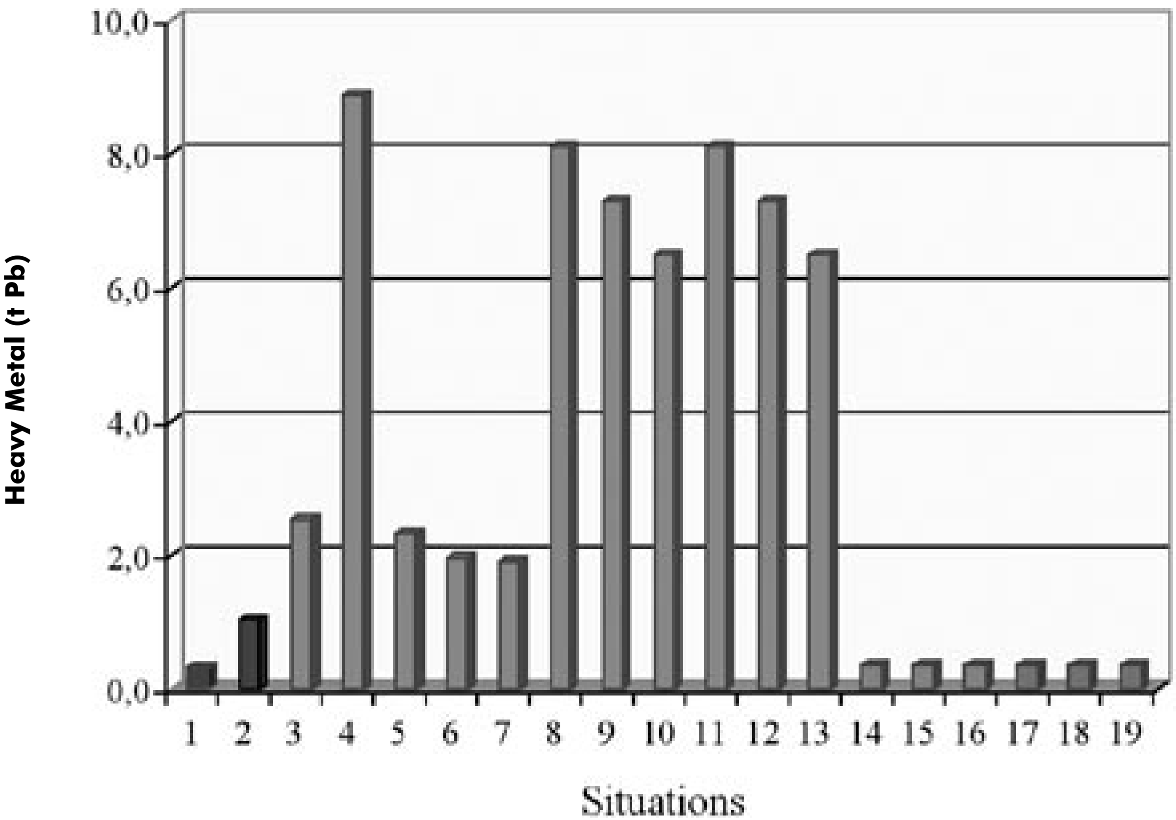

Fig. 11: Total heavy metals emissions for the different situations studied.

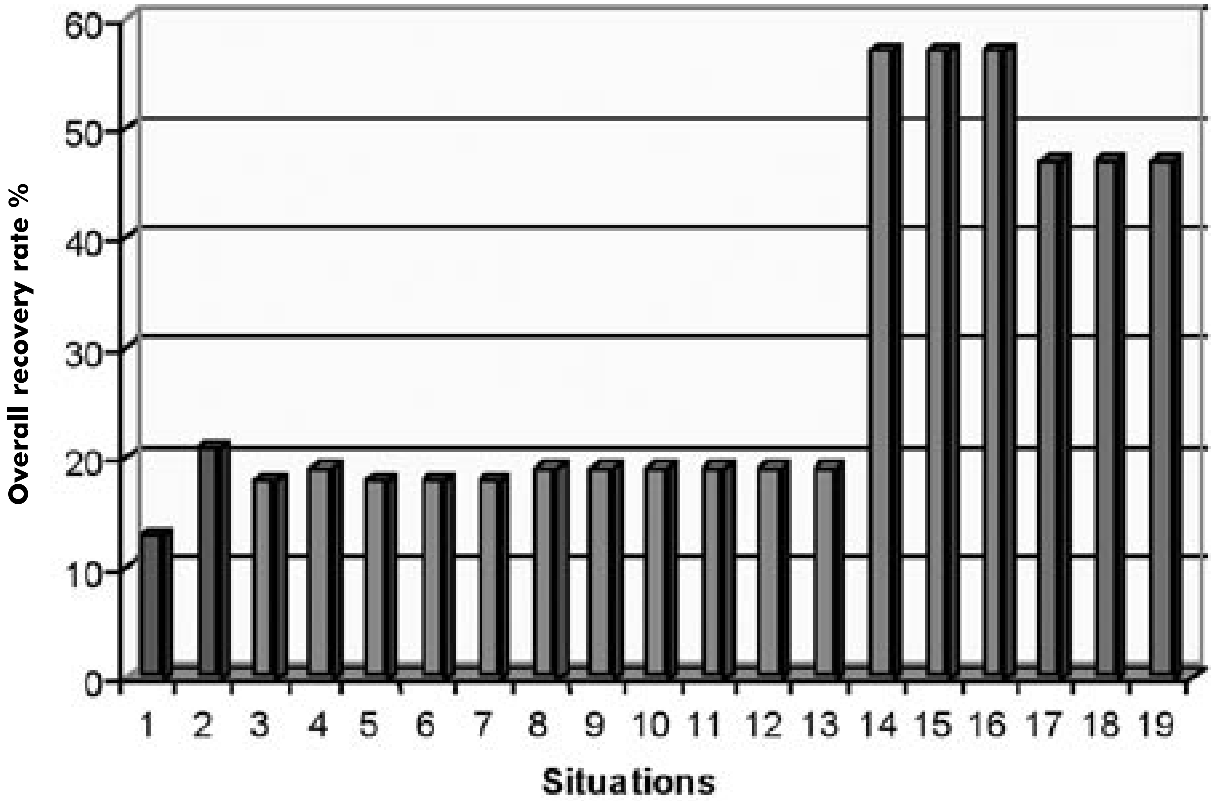

Fig. 12: Overall recovery rate of materials for the different situations studied.

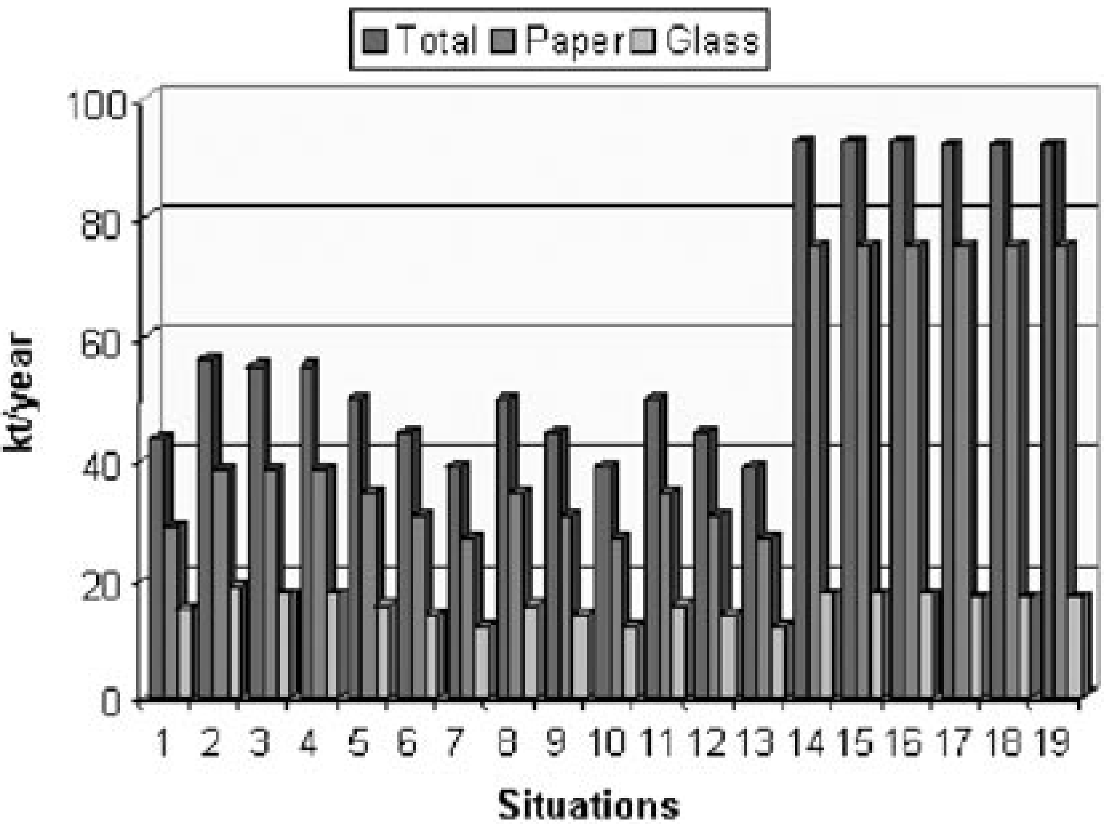

Fig. 13: Recovery of glass and paper in the different situations studied

while the emissions of dioxins, furans and heavy metals are substantially higher in incineration than in the remaining alternatives.

The highest recovery rates of materials are achieved employing composting (57%), slightly higher than that of biomethanisation (47%) and at quite a distance from the alternatives employing incineration (18-20%). The lowest recovery rate corresponds to the current situation, with only 13%.

The results of the normalisation and weighting of the different environmental impacts when applying the Ecoindicator 95 model show quite similar values for the options that include selective collection with landfilling-recovery of biogas, biomethanisation or composting, this last option presenting a slighter lower impact. The option including incineration presents a much higher impact, mainly due to the large values of the normalisation factors assigned to the emissions of heavy metals and carcinogenic substances in comparison with the greenhouse effect, acidification, eutrophication or smog.

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